Varying constants entropic cosmology

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Varying constants cosmologies

- Are alternative to inflationary cosmology
  - → Can solve all the cosmological problems (horizon, flatness, monopole, singularity)
  - → Varying speed of light and varying gravitational constant theories are one of the most explored
  - → There is not any direct observational evidence of varying speed of light but there are many indirect evidences. For instance, the fine structure constant $\alpha = \frac{e^2}{\hbar c}$ is suggested to change and it involves the speed of light c as well.

Entropic cosmology

- Curvature of the space-time proportional to the stress energy + surface terms (entropic terms)
- Gravity is still the fundamental force here

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = \frac{8\pi G}{c^4} T_{\mu\nu} + \text{Entropic Terms}$$

- The acceleration equation will be

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}\left[\rho + \frac{3p}{c^2}\right] + C_H H^2 + C_{\dot{H}} \dot{H}.$$

- Entropic force terms (boundary terms) are supposed to be responsible for the current acceleration as well as for an early exponential expansion of the universe

Entropic force field equations and varying constants

- The main idea of our consideration is to assume homogeneous Friedmann geometry and generalize field equations which contain the entropic force terms $f(t)$ and $g(t)$ onto the case of varying speed of light c and varying Newton gravitational constant G theories. The modified Einstein equations can be written down as follows

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G(t)}{3}\rho - \frac{kc^2(t)}{a^2} + f(t),$$

$$\frac{\ddot{a}}{a} = -\frac{4\pi G(t)}{3}\left[\rho + \frac{3p}{c^2(t)}\right] + g(t).$$

- The modified continuity equation reads as

$$\dot{\rho} + 3H\left[\rho + \frac{p}{c^2(t)}\right] + \rho\frac{\dot{G(t)}}{G(t)} - 3\frac{kc(t)\dot{c}(t)}{4\pi G(t)a^2(t)} = \frac{3H}{4\pi G(t)}\left[g(t) - f(t) - \frac{\dot{f}(t)}{2H}\right],$$

Gravitational thermodynamics and varying constants

- We generalize the Hawking temperature T and Bekenstein entropy S for the varying c and G theories

$$T = \frac{\gamma\hbar c(t)}{2\pi k_B r_h(t)}, \quad S = \frac{k_B}{4\hbar}\left[\frac{c^3(t)A(t)}{G(t)}\right],$$

where $A(t) = 4\pi r_h^2(t)$ is the horizon area and γ is an arbitrary and non-negative parameter, theoretically assummed to be the order of unity $O(1)$

- By using the first law of thermodynamics for non adiabatic expansion of the universe

$$\frac{dE}{dt} + p\frac{dV}{dt} = T\frac{dS}{dt},$$

we get the modified continuity equation as follows

$$\dot{\rho} + 3H\left[\rho + \frac{p}{c^2(t)}\right] = -2\frac{\dot{c}(t)}{c(t)}\rho + \frac{3\gamma H^2}{8\pi G(t)}\left[\left(5\frac{\dot{c}(t)}{c(t)} - \frac{\dot{G}(t)}{G(t)}\right) - 2\frac{\dot{H}}{H}\right]$$

where horizon radius, $r_h(t) \equiv \frac{c(t)}{H(t)}$, $\dot{V}(t) = 3V(t)H(t)$ and $E(t) = \varepsilon(t)V(t)$, $\varepsilon(t) = \rho(t)c^2(t)$.

Modified field equations

- We can define the functions $f(t)$ and $g(t)$ as

$$f(t) = \gamma H^2, \;\; g(t) = \gamma H^2 + \frac{\gamma}{2}\left(5\frac{\dot{c}(t)}{c(t)} - \frac{\dot{G}(t)}{G(t)}\right)H + \frac{4\pi G(t)}{3H}\left(\frac{\dot{G}(t)}{G(t)} - 2\frac{\dot{c}(t)}{c(t)}\right)\rho$$

- By using these general functions we have modied field equations

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G(t)}{3}\rho + \gamma H^2$$

$$\frac{\ddot{a}}{a} = \gamma H^2 - \frac{4\pi G(t)}{3}\left(\rho + \frac{3p}{c^2(t)}\right) + \left(\frac{7\gamma - 2}{2}\right)\frac{\dot{c}(t)}{c(t)}H + \left(\frac{1 - 2\gamma}{2}\right)\frac{\dot{G}(t)}{G(t)}H$$

Observational parameters

- In the multiple fluid scenario, using barotropic equation of state $p_i = w_i\rho_i$, the continuity equation takes the form

$$\dot{\rho}_i + 3H\rho_i(1 + w_i) = -2\frac{\dot{c}}{c}\rho_i + \frac{\gamma}{1-\gamma}\rho_i\left[\left(5\frac{\dot{c}(t)}{c(t)} - \frac{\dot{G}(t)}{G(t)}\right) - 2\frac{\dot{H}}{H}\right]$$

- The solution for each fluid, once we use our ansätze, $c = c_0 a^n$ and $G = G_0 a^q$, is:

$$\rho_i = \frac{\rho_0}{H_0^{\frac{2\gamma}{1-\gamma}}} H^{\frac{2\gamma}{1-\gamma}} a^{f_i^X(\gamma,n,q)}$$

Varying $c = c_0 a^n$

$$f_i^c(\gamma, n) = -3\left[1 + w_i + \tfrac{n(2-7\gamma)}{3(1-\gamma)}\right]$$

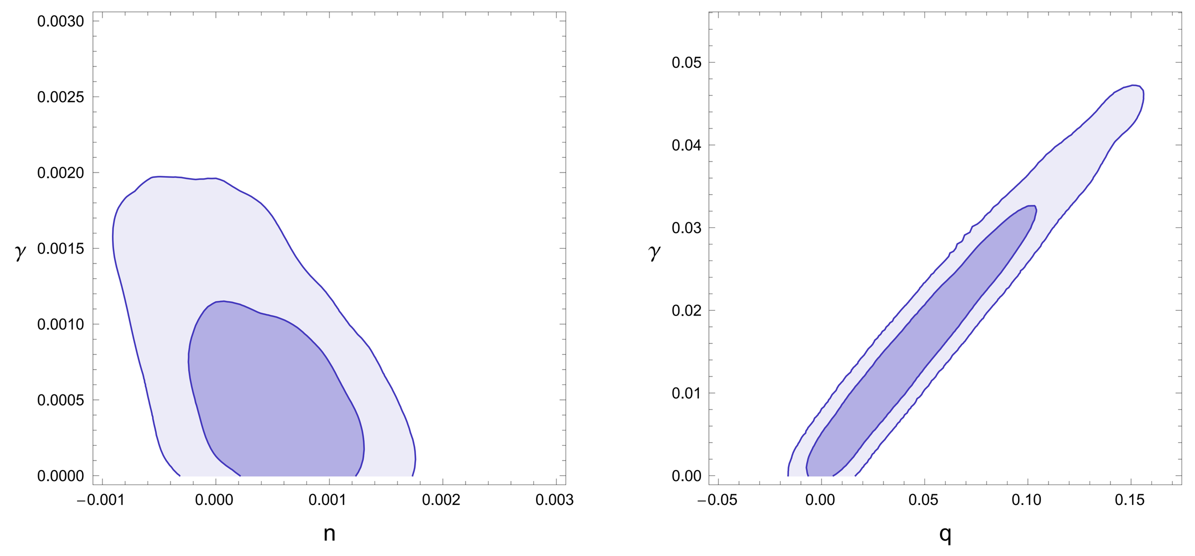
$$E^2 = \left(\frac{H}{H_0}\right)^2 = \left[\sum_i \tfrac{\Omega_{i,0}}{1-\gamma} a^{f_i^c}(\gamma, n)\right]^{\frac{\gamma-1}{2\gamma-1}}$$

Varying $G = G_0 a^q$

$$f_i^G(\gamma, q) = -3\left[1 + w_i + \tfrac{q\gamma}{3(1-\gamma)}\right]$$

$$E^2 = \left(\frac{H}{H_0}\right)^2 = \left[a^q \sum_i \tfrac{\Omega_{i,0}}{1-\gamma} a^{f_i^G}(\gamma, q)\right]^{\frac{\gamma-1}{2\gamma-1}}$$

Data analysis: SNeIa, BAO and CMB



Observational parameters of the entropic models under study:

id.	Ω_m	Ω_b	h	q/n	γ	α	β	$\mathcal{M}_B^1$	Δ_m
$G = G_0\, a^q$	$0.314^{+0.009}_{-0.008}$	$0.0453^{+0.0009}_{-0.0009}$	$0.698^{+0.007}_{-0.007}$	$0.048^{+0.042}_{-0.033}$	< 0.022	$0.141^{+0.007}_{-0.006}$	$3.106^{+0.077}_{-0.087}$	$-19.044^{+0.018}_{-0.019}$	$-0.071^{+0.023}_{-0.023}$
$c = c_0\, a^n$	$0.311^{+0.007}_{-0.007}$	$0.046^{+0.001}_{-0.001}$	$0.696^{+0.007}_{-0.007}$	$0.00049^{+0.00049}_{-0.00053}$	< 0.0007	$0.141^{+0.007}_{-0.007}$	$3.100^{+0.080}_{-0.080}$	$-19.043^{+0.018}_{-0.018}$	$-0.070^{+0.023}_{-0.022}$

(*Left panel.*) Varying $c = c_0 a^n$ scenario: 68% and 95% confidence levels for n and γ.
(*Right panel.*) Varying $G = G_0 a^q$ scenario: 68% and 95% confidence levels for q and γ.

References

[1] M. P. Dąbrowski, H.G., and V. Salzano., *Varying Constants–ΛCDM Cosmology*, arXiv:1503.08722.

[2] M. P. Dąbrowski and H.G., Phys. Lett. B748, 428 (2015).

[3] J. K. Webb, J. A. King, M. T. Murphy, V. V. Flambaum, R. F. Carswell and M. B. Bainbridge, Phys. Rev. Lett. 107, 191101 (2011)

[4] D. A. Easson, P. H. Frampton, and G. F. Smoot, Phys. Lett. B696, 273 (2011); Int. J. Mod. Phys. A 27, 125066 (2012).

[5] J. Moffat, Int. J. Mod. Phys. D 2, 351 (1993); A. Albrecht and J. Magueijo, Phys. Rev D 59, 043516 (1999); J.D. Barrow, Phys. Rev. D 59, 043515 (1999).